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Huang

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(54) **PHASE CHANGE MEMORY DEVICES AND METHODS FOR MANUFACTURING THE SAME**

(58) **Field of Classification Search** 257/536, 257/537, E21.495; 365/46, 100
See application file for complete search history.

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(30) **Foreign Application Priority Data**

Mar. 27, 2007 (TW) 96110500 A

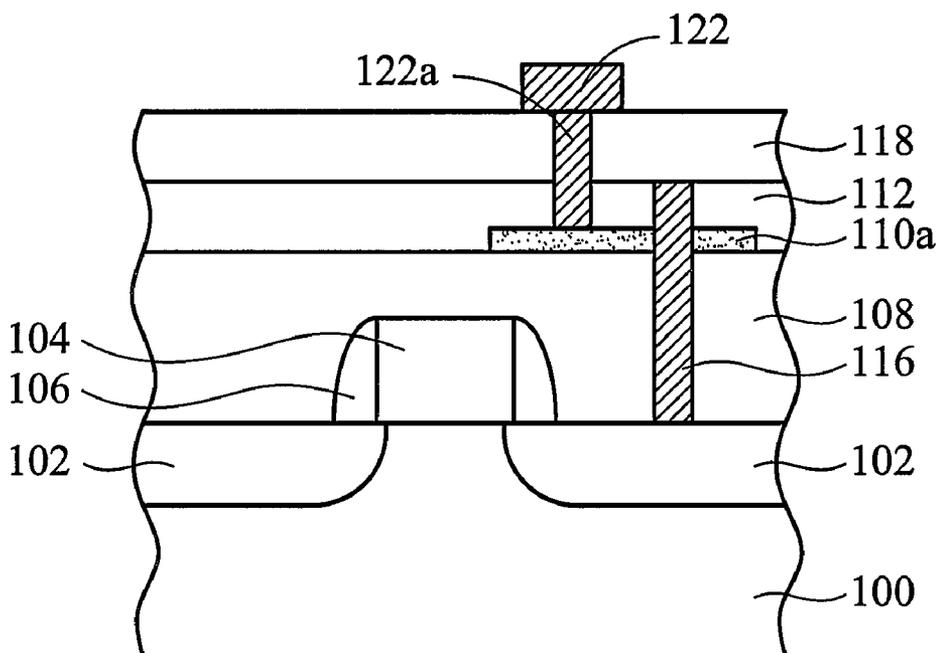
(51) **Int. Cl.**
H01L 29/00 (2006.01)

(52) **U.S. Cl.** 257/537; 257/536; 257/E21.495; 365/46; 365/100

(57) **ABSTRACT**

Phase change memory devices and methods for manufacturing the same are provided. An exemplary embodiment of a phase change memory device comprises a substrate. A dielectric layer is formed over the substrate and a phase change material layer is embedded in the dielectric layer. A first conductive electrode is also embedded in the dielectric layer to penetrate the phase change material layer and extends perpendicular to a top surface of the dielectric layer.

12 Claims, 14 Drawing Sheets



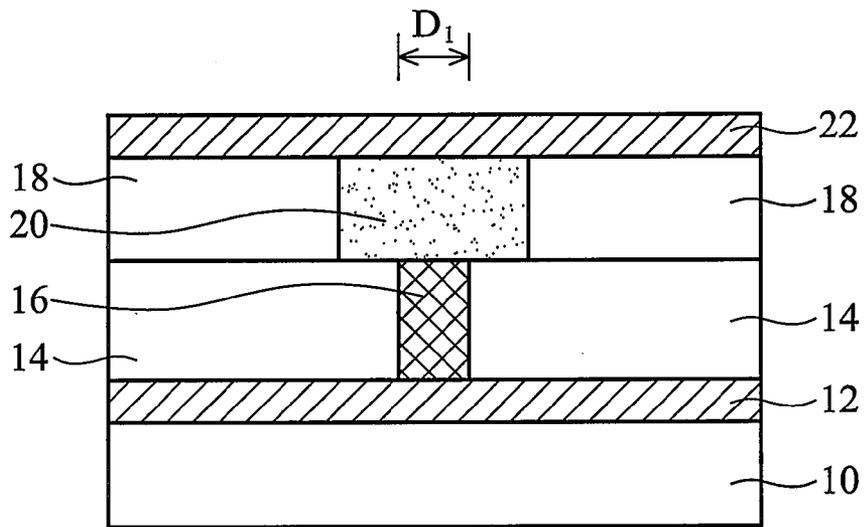


FIG. 1 (PRIOR ART)

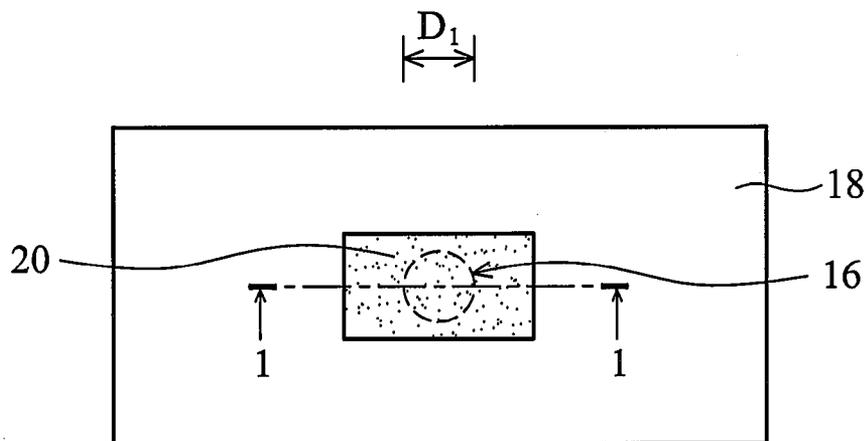


FIG. 2 (PRIOR ART)

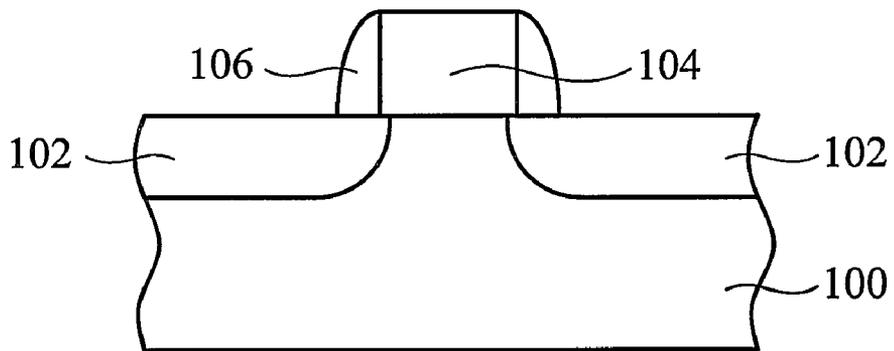


FIG. 3

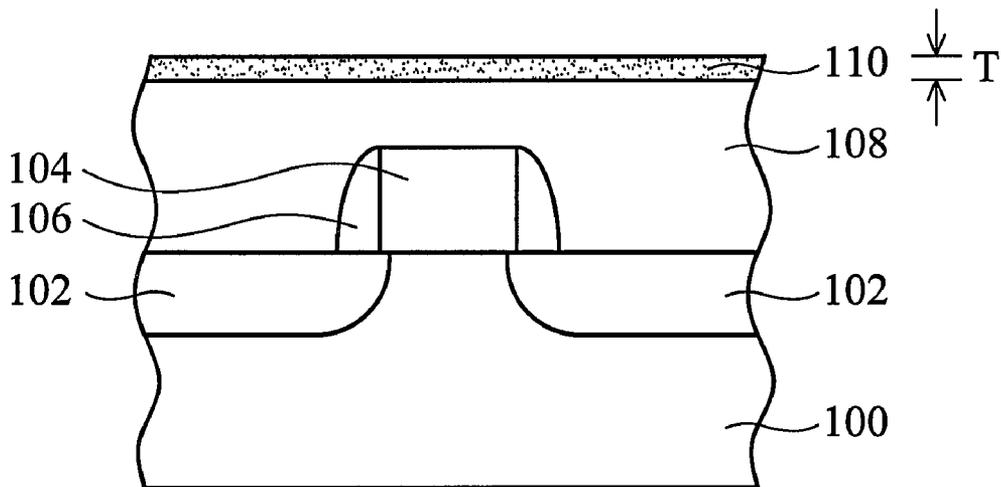


FIG. 4

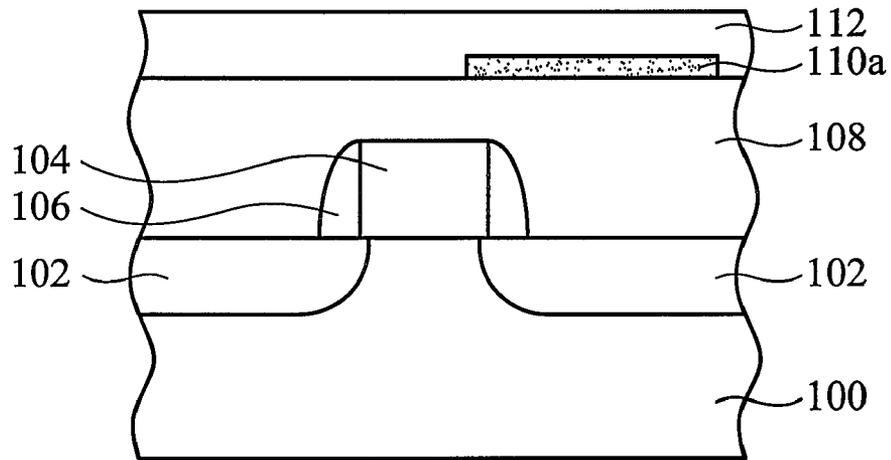


FIG. 5

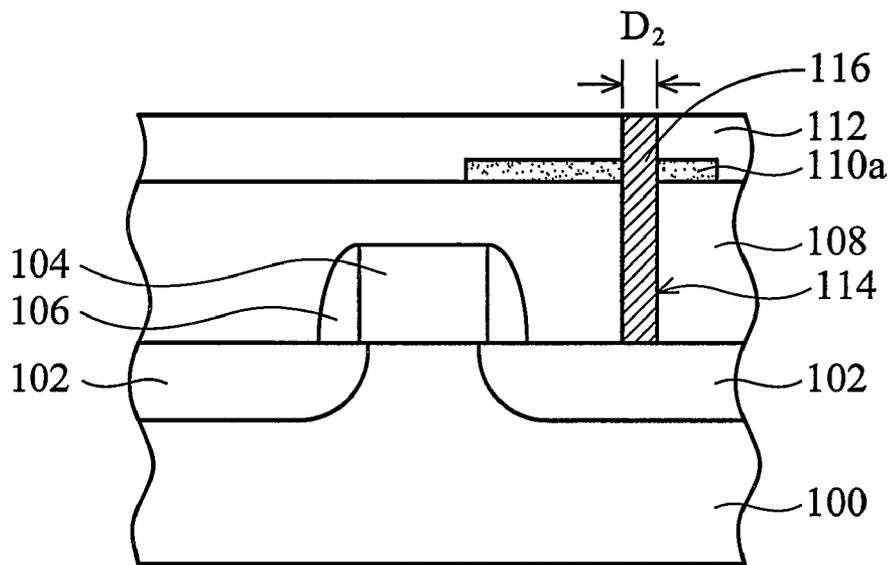


FIG. 6

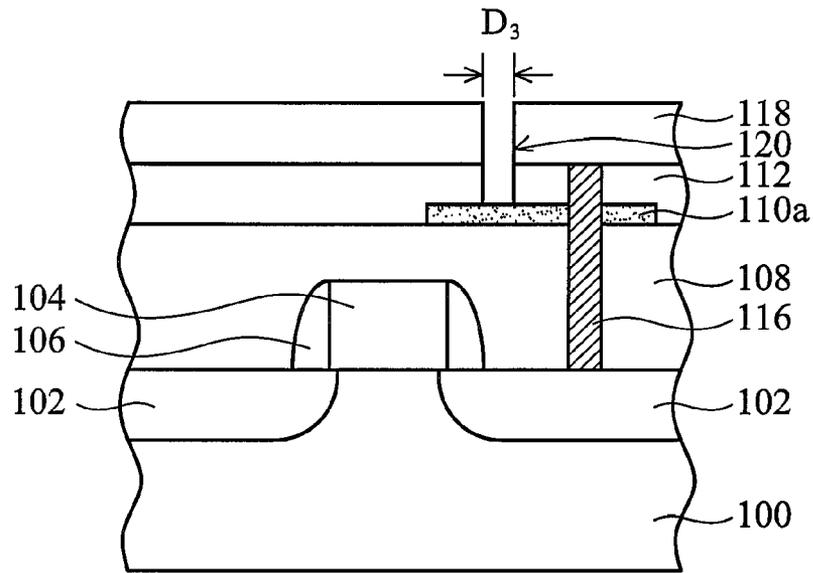


FIG. 7

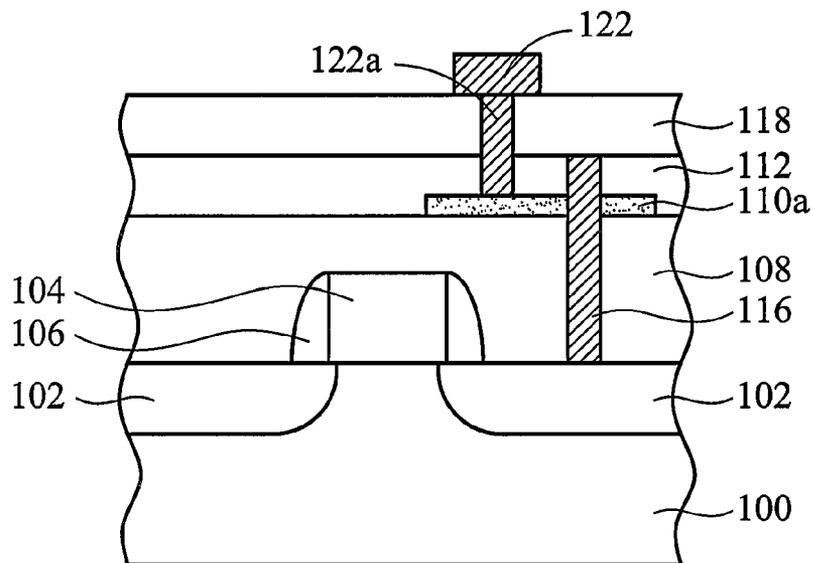


FIG. 8

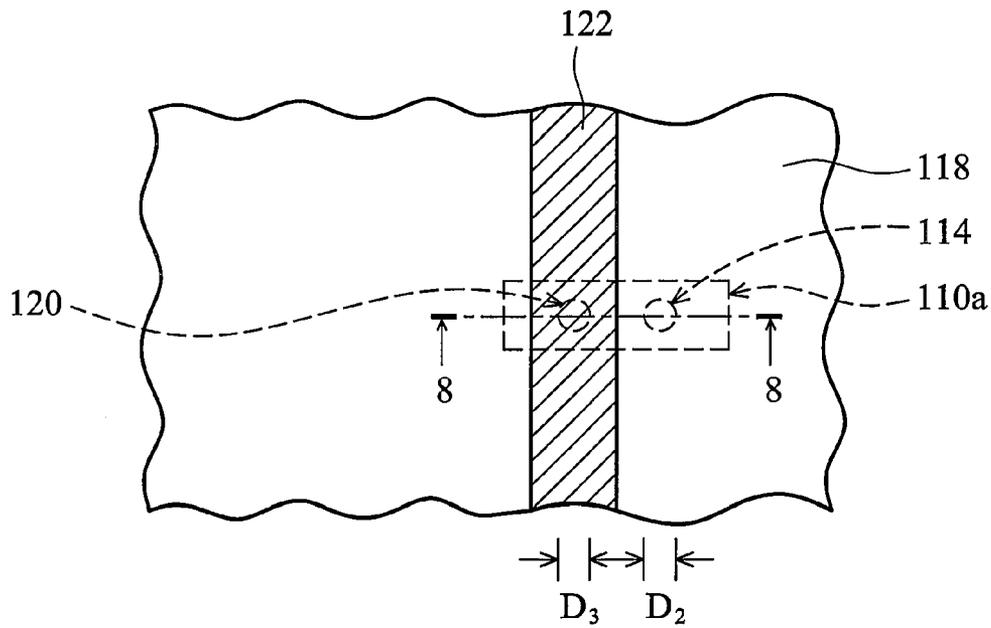


FIG. 9

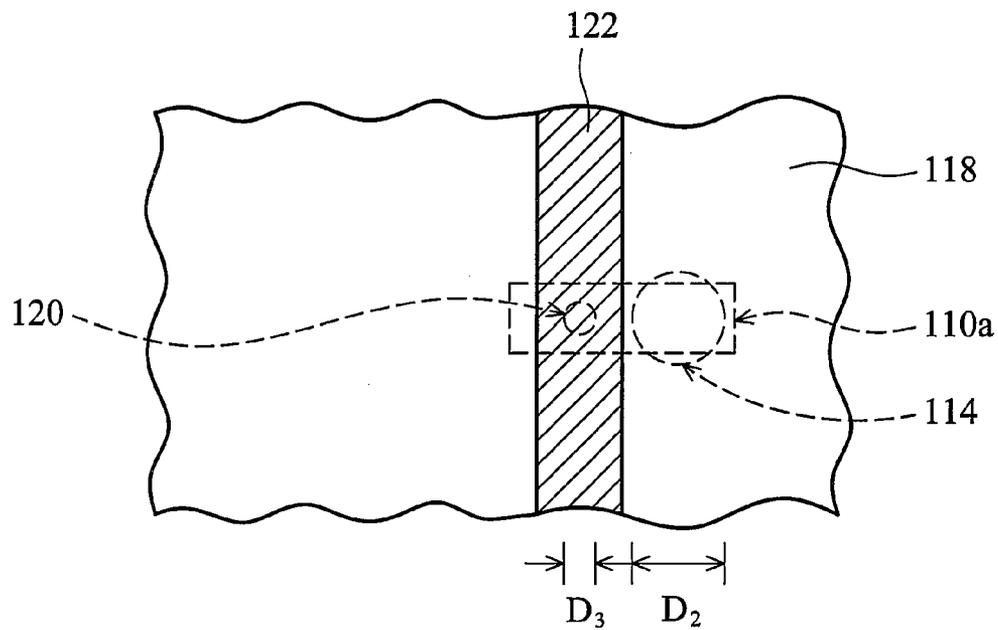


FIG. 10

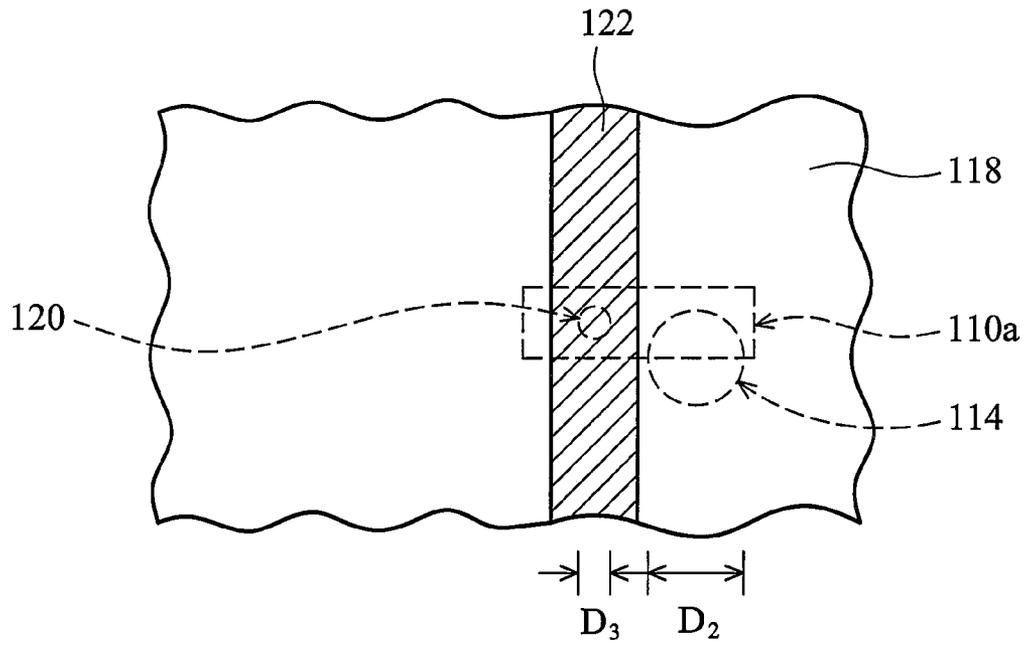


FIG. 11

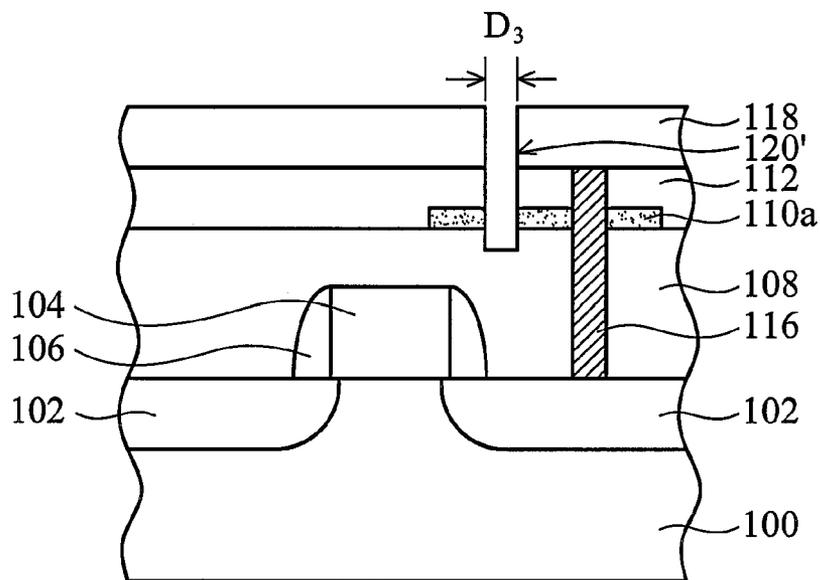


FIG. 12

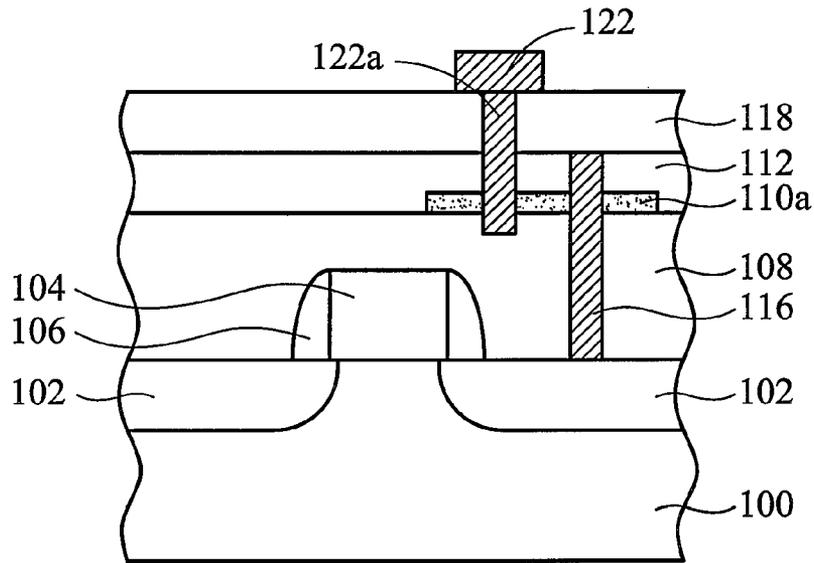


FIG. 13

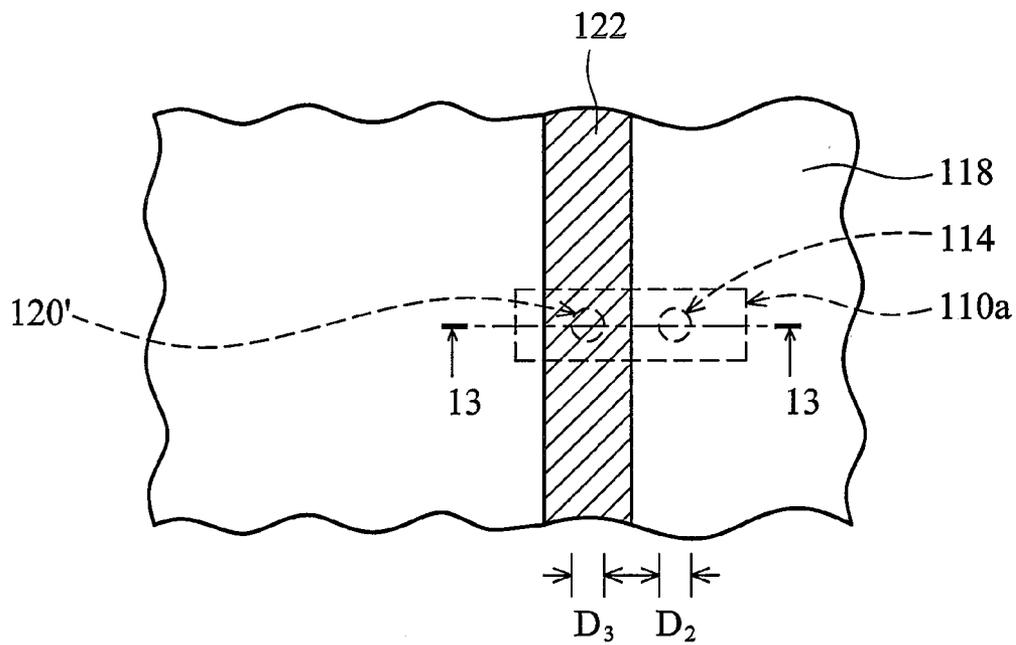


FIG. 14

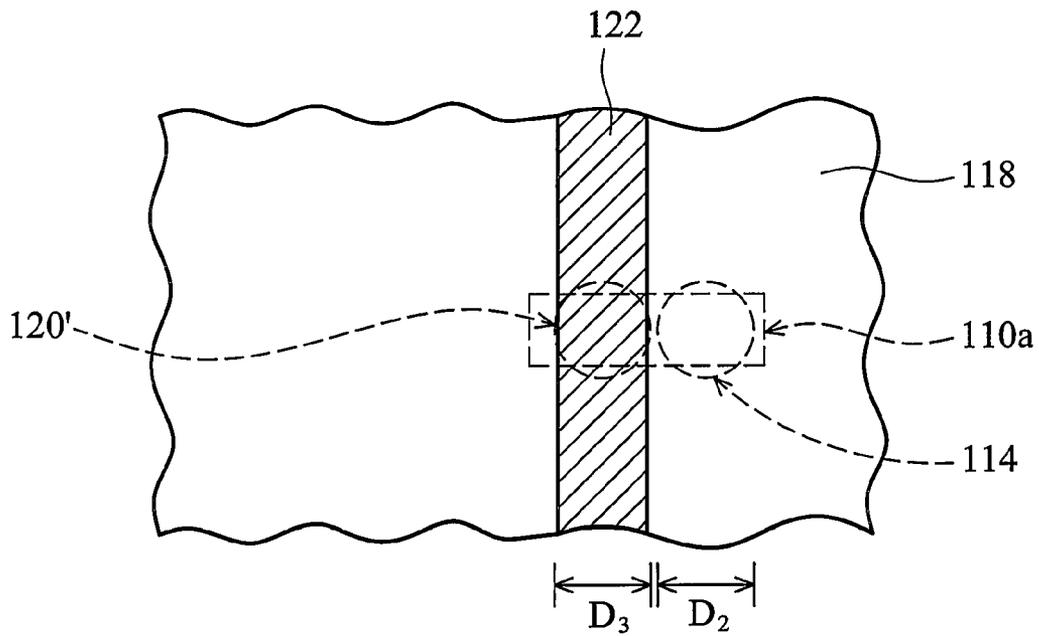


FIG. 15

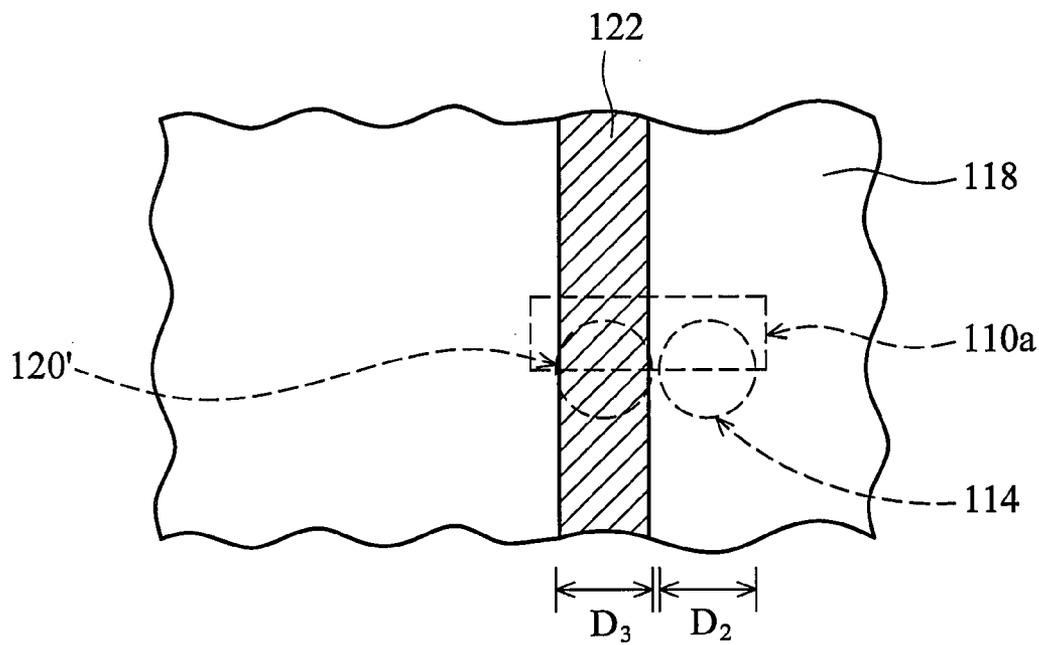


FIG. 16

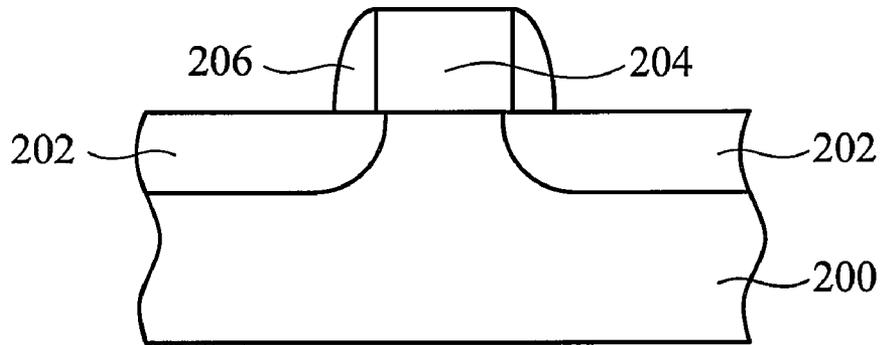


FIG. 17

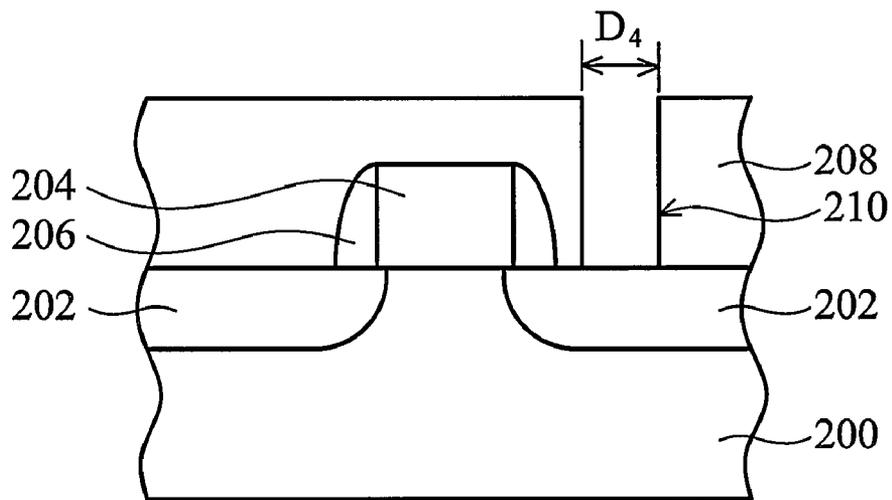


FIG. 18

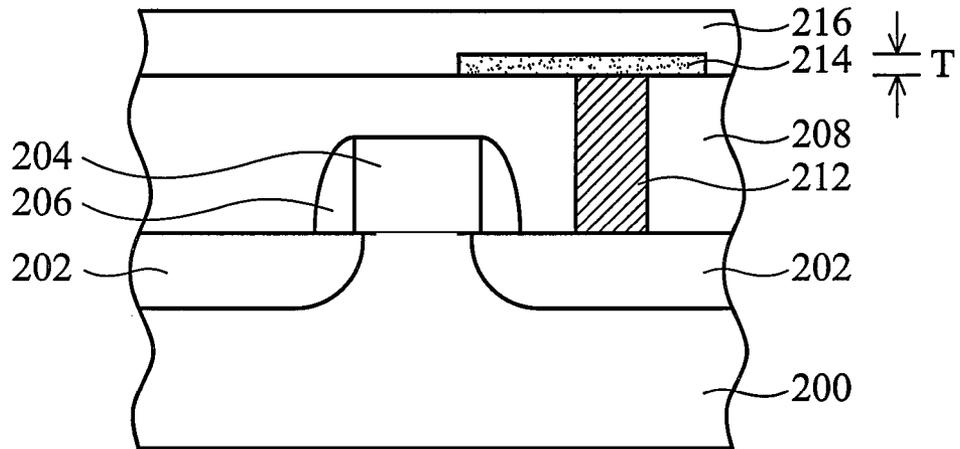


FIG. 19

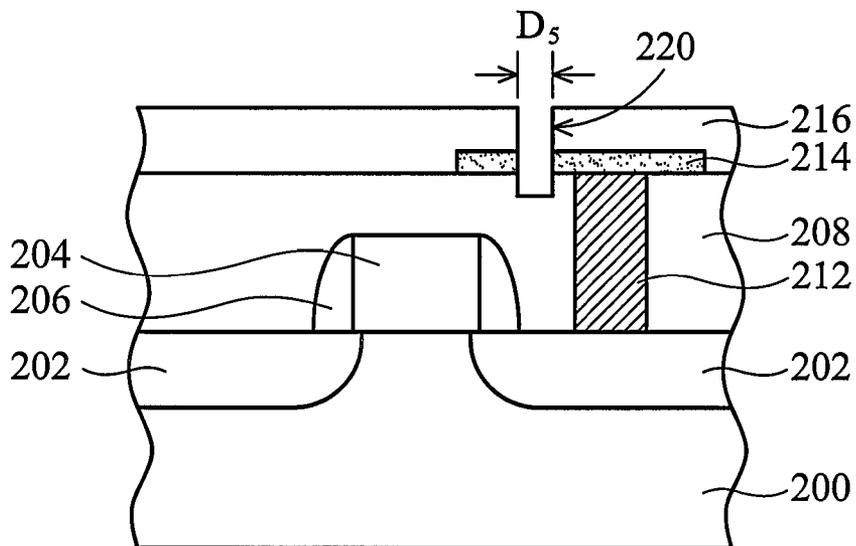


FIG. 20

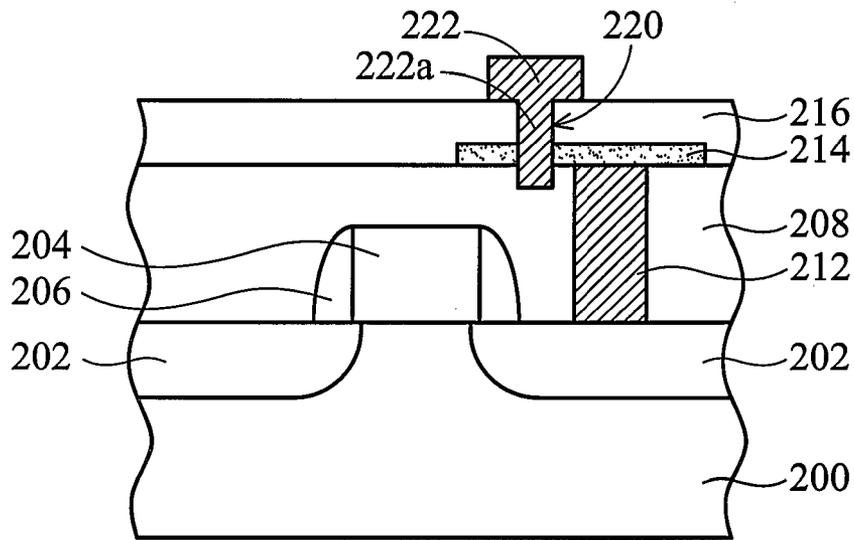


FIG. 21

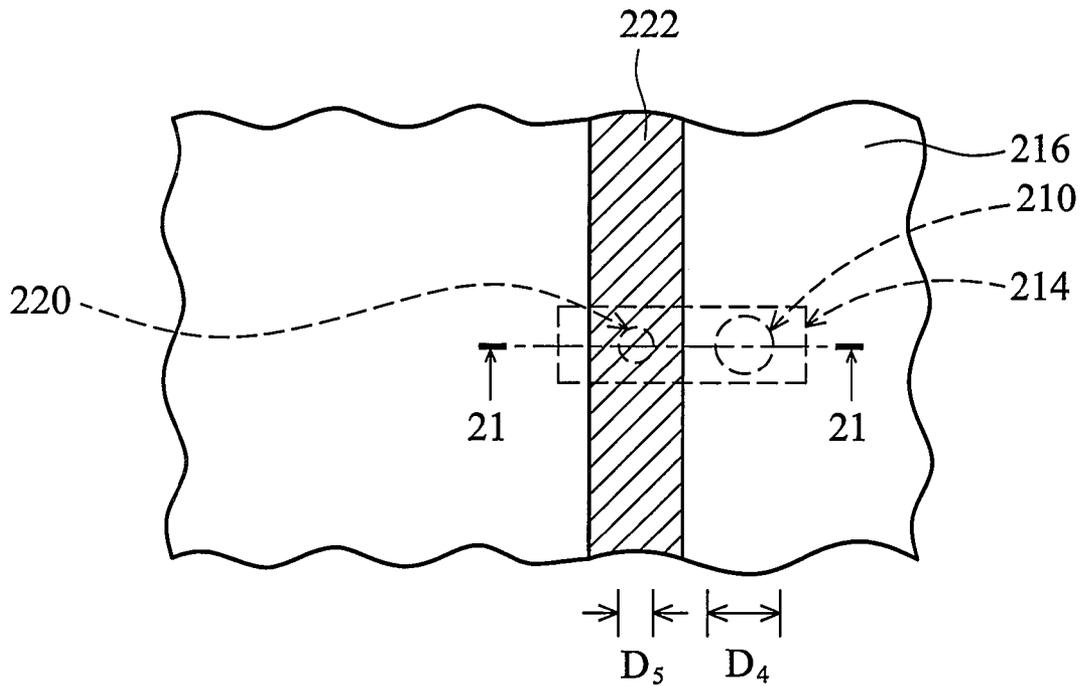


FIG. 22

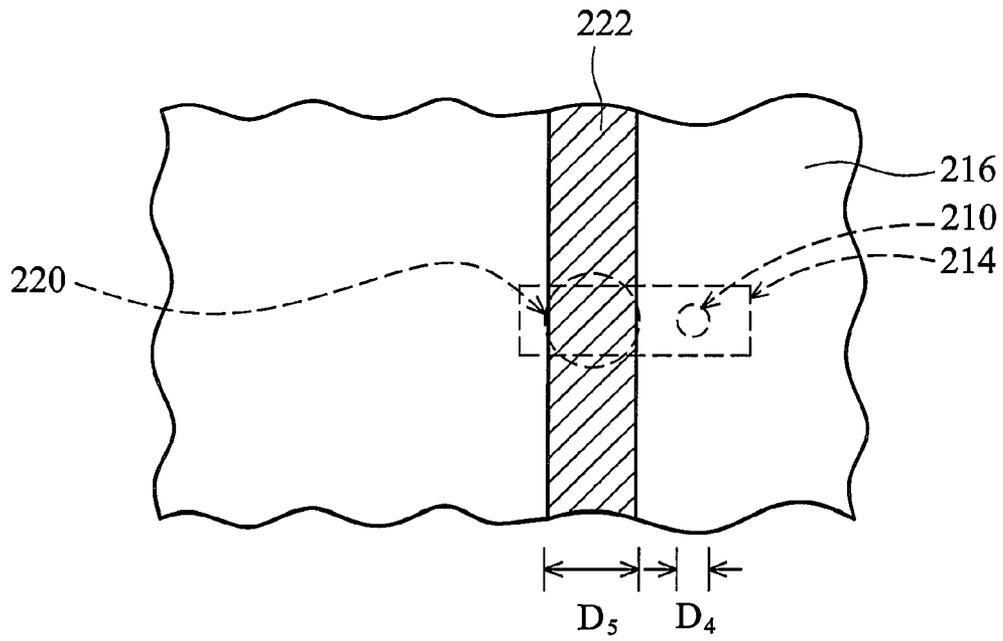


FIG. 23

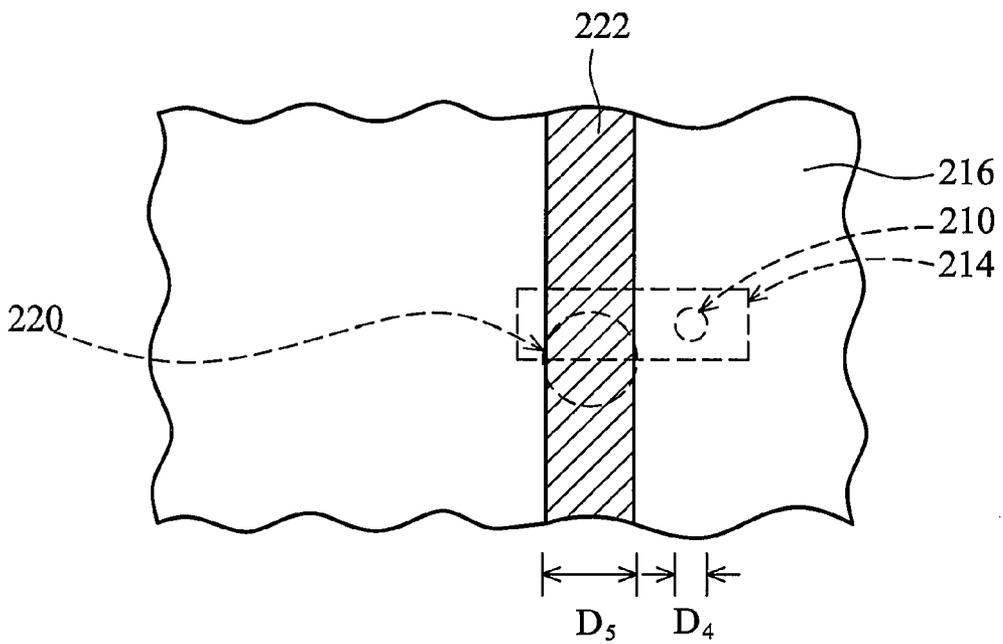


FIG. 24

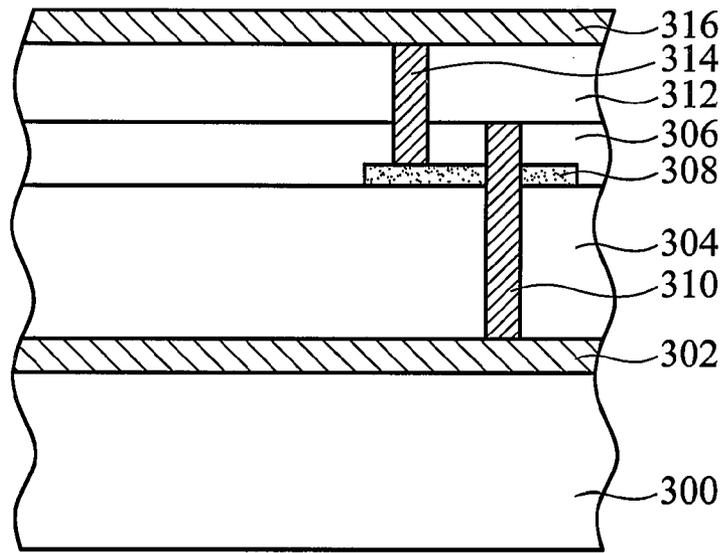


FIG. 25

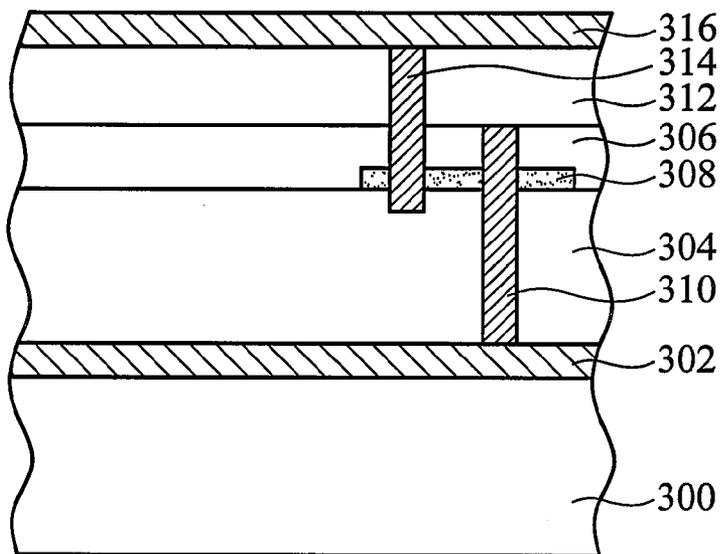


FIG. 26

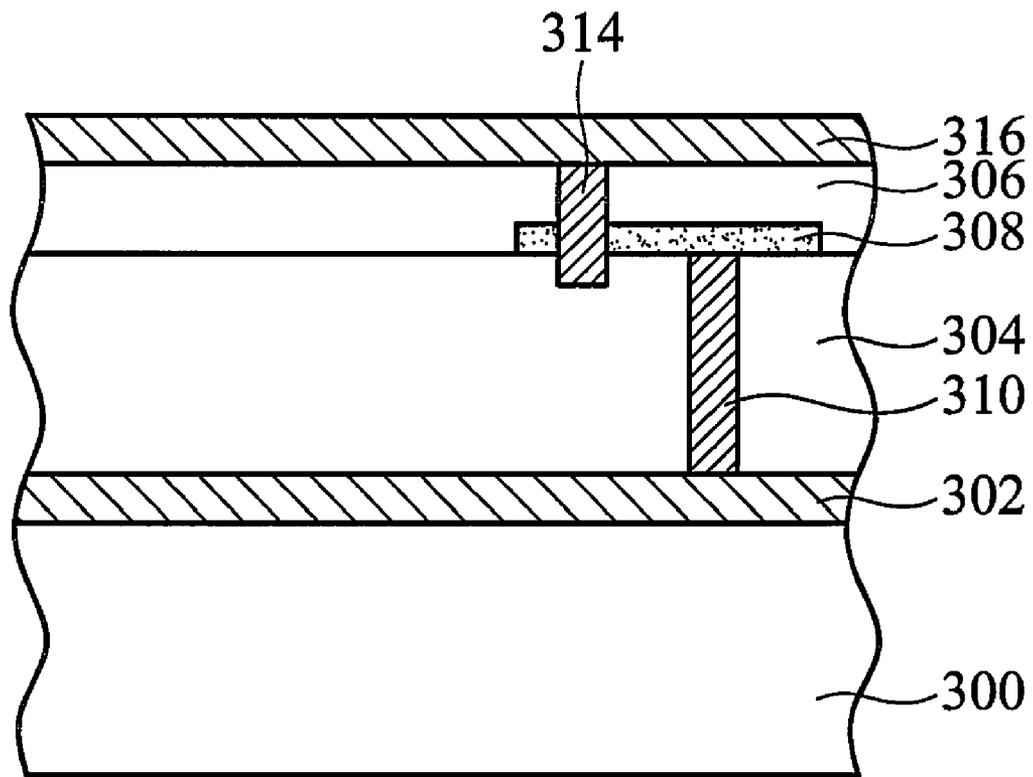


FIG. 27

**PHASE CHANGE MEMORY DEVICES AND
METHODS FOR MANUFACTURING THE
SAME**

BACKGROUND

The invention relates to memory devices and more particularly to phase change memory devices and a method for fabricating the same.

Phase change memory devices are non-volatile, highly readable, highly programmable, and require a lower driving voltage/current. Current trends in phase change memory development are to increase cell density and reduce current density thereof.

Phase change material in a phase change memory device has at least two solid phases, a crystalline state and an amorphous state. Transformation between these two phases can be achieved by changing the temperature of the phase change material. The phase change material exhibits different electrical characteristics depending on its state. For example, in its amorphous state the material exhibits a higher resistivity than in the crystalline state. Such phase change material may switch between numerous electrically detectable conditions of varying resistivity on a nanosecond time scale with the input of pico joules of energy. Chalcogenide material is a popular and widely used phase change material in modern phase change memory technology.

Since phase change material allows a reversible phase transformation, memory bit status can be distinguished by determining the phase of phase change material in the memory bit.

FIG. 1 is a schematic diagram of a cross section of a conventional phase change memory cell, in which the phase change memory cell includes a bottom electrode 12 formed over a substrate 10. The bottom electrode 12 is disposed over an insulating layer (not shown) formed over the substrate 10. An insulating layer 14 is formed over the substrate 10, having a heating electrode 16 formed in a part therein. Another insulating layer 18 is formed over the insulating layer 14, having a phase change material layer 20 formed in a part therein. The phase change material layer 20 penetrates the insulating layer 18 and partially contacts the heating electrode 16 thereunder. A top electrode 22 is formed over the insulating layer 18 and contacts a top surface of the phase change material layer 20. In FIG. 1, the heating electrode 16 is formed as an electrode of a plug configuration, having a diameter D_1 . Thus, the heating electrode 16 and the phase change material layer 20 formed thereover have a contact surface of about $\pi D_1^2/4$ therebetween. FIG. 2 is a schematic diagram showing a top view of the phase change memory cell illustrated in FIG. 1 but without the top electrode 22. FIG. 1 is a cross section taken along line 1-1 in FIG. 2.

During writing mode, currents are generated by the heating electrode 16 to heat an interface between the phase change material layer 20 and the heating electrode 16, thereby transforming a portion (not shown) of the phase change material layer 20 into amorphous phase or crystalline phase depending on currents through the heating electrode 16 and times for heating the phase change material layer 20.

The phase change memory cell illustrated in FIG. 1 has disadvantages such as strong current needed to successfully transform the phase of the phase change materials during writing mode, such that current density applied to the phase change material layer 20 must be increased. One way to increase the current density is to lower the contact surface between the heating electrode 16 and the phase material layer 20 and this is usually achieved by lowering a lateral dimen-

sion of the heating electrode 16, such as by lowering the diameter D_1 of the heating electrode 16 in FIG. 1.

Nevertheless, reduction of the dimension of the heating electrode 16 is limited by current photolithography ability, limiting size reduction of the heating electrode 16 and increase in current density applied thereto.

SUMMARY

Phase change memory devices and methods for manufacturing the same are provided to thereby solve those issues of the conventional phase change memory devices.

An exemplary embodiment of a phase change memory device comprises a substrate. A dielectric layer is formed over the substrate and a phase change material layer is embedded in the dielectric layer. A first conductive electrode is also embedded in the dielectric layer to penetrate the phase change material layer and extends perpendicular to a top surface of the dielectric layer.

An exemplary embodiment of a method for manufacturing a phase change memory device comprises providing a substrate. A first dielectric layer is formed over the substrate. A phase change material layer is formed over a part of the first dielectric layer. A second dielectric layer is formed over the first dielectric layer and covering the phase change material layer. A first opening is formed to penetrate the second dielectric layer, the phase change material layer, and the first dielectric layer perpendicular to a top surface of the substrate. A first conductive electrode is formed in the first opening. A third dielectric layer is formed over the second dielectric layer and the first conductive electrode. A second opening is formed to penetrate the third dielectric layer and the second dielectric layer perpendicular to a top surface of the substrate and exposing a part of the phase change material layer. A second conductive electrode is formed in the second opening.

Another exemplary embodiment of a method for manufacturing a phase change memory device comprises providing a substrate. A first dielectric layer is formed over the substrate. A first opening is formed to penetrate the first dielectric layer perpendicular to a top surface of the substrate and exposing a part of the substrate. A first conductive electrode is formed in the first opening. A phase change material layer is formed over a part of the first dielectric layer and covers the first conductive electrode. A second dielectric layer is formed over the first dielectric layer overlying the phase change material layer. A third dielectric layer is formed over the second dielectric layer. A second opening is formed to penetrate the third dielectric layer and the second dielectric layer perpendicular to the top surface of the substrate, and the second opening exposes a part of the phase change material layer. A second conductive electrode is formed in the second opening.

A detailed description is given in the following embodiments with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention can be more fully understood by reading the subsequent detailed description and examples with references made to the accompanying drawings, wherein:

FIG. 1 is a schematic diagram showing a cross section of a conventional phase change memory cell;

FIG. 2 is a schematic showing a schematic top view of the conventional PCM cell of FIG. 1;

FIGS. 3-8 are schematic diagrams showing different manufacturing steps of a PCM device according to an embodiment of the invention;

FIGS. 9-11 are schematic diagrams showing a top view of a PCM device of the invention, respectively;

FIGS. 12-13 are schematic diagrams showing different manufacturing steps of a PCM device according to another embodiment of the invention;

FIGS. 14-16 are schematic diagrams showing a top view of a PCM device of the invention, respectively;

FIGS. 17-21 are schematic diagrams showing different manufacturing steps of a PCM device according to another embodiment of the invention;

FIGS. 22-24 are schematic diagrams showing a top view of a PCM device of the invention, respectively; and

FIGS. 25-27 are schematic diagrams showing a cross section of a passive PCM device of the invention, respectively.

DESCRIPTION

The following description is of the best-contemplated mode of carrying out the invention. This description is made for the purpose of illustrating the general principles of the invention and should not be taken in a limiting sense. The scope of the invention is best determined by reference to the appended claims.

Embodiments of phase change memory devices and methods for manufacturing the same are described as below incorporating FIGS. 3-27, wherein FIGS. 3-11 are schematic diagrams showing fabrication steps in a method for manufacturing a phase change memory device according to a first exemplary embodiment, respectively. FIGS. 12-16 are schematic diagrams showing fabrication steps in a method for manufacturing a phase change memory device according to a second exemplary embodiment, respectively. FIGS. 17-24 are schematic diagrams showing fabrication steps of a method for manufacturing a phase change memory device according to a third exemplary embodiment, respectively. FIGS. 25-27 are schematic diagrams showing fabrication steps of a method for manufacturing a phase change memory device according to a fourth exemplary embodiment.

FIRST EMBODIMENT

In FIG. 3, a substrate **100**, for example a silicon semiconductor substrate, is first provided. Herein, an active device, such as a transistor, is also formed over the substrate **100**. As shown in FIG. 3, the transistor has a pair of source/drain regions **102** formed in portions of the substrate **100** and a gate structure **104** formed over the portion of the substrate **100** between the source/drain regions **102**. As shown in FIG. 3, the gate structure **104** may include a gate dielectric layer and a conductive layer but is merely illustrated as a gate structure **104** here for simplicity. A spacer **106** is disposed over opposing sidewalls of the gate structure **104**. The transistor illustrated in FIG. 3 may be a P type or an N type transistor and the source/drain regions **102** may comprise P type or N type impurities depending on the conductivity type of the transistor.

In FIG. 4, a dielectric layer **108** is blanketly formed over the substrate **100**, covering the transistor, and a phase change material layer **110** is then blanketly formed over the dielectric layer **108**. The dielectric layer **108** may comprise borophosphosilicate glass (BPSG), silicon oxide or spin on glass (SOG), and may be formed by methods such as chemical vapor deposition (CVD) or spin-on techniques. The phase change material layer **110** may comprise chalcogenide materials such as Ge—Sb—Te trinary chalcogenide compound or Ge—Te, Te—Sb binary chalcogenide compounds and can be formed by methods such as CVD or sputtering. Herein, the

phase change material layer **110** may have a thickness T of about 50-1000 Å, preferably of about 100-150 Å.

In FIG. 5, a photolithography step and an etching step (both not shown) are sequentially performed through the use of a first photomask (not shown) to pattern the phase change material layer **110**, thereby leaving a patterned phase change material layer **110a** over a part of the dielectric layer **108**. Next, a dielectric layer **112** is formed over the dielectric layer **108** and covers the patterned phase change material layer **110a** overlying the dielectric layer **108**. The dielectric layer **112** may comprise borophosphosilicate glass (BPSG), silicon oxide or spin on glass (SOG) and can be formed by methods such as chemical vapor deposition (CVD) or spin-on techniques.

In FIG. 6, a photolithography step and an etching step (not shown) are sequentially performed through the use of a second photomask (not shown) to thereby define the dielectric layer **112**, the phase change material layer **110a** and the dielectric layer **108**, thereby forming an opening **114** in a part of these layers. Herein, the opening **114** sequentially penetrates the dielectric layer **112**, the phase change material layer **110a** and the dielectric layer **108** perpendicular to a top surface of the substrate **100**, thereby exposing a part of the substrate **100**. In some embodiments, the opening **104** may be substantially formed over one of the source/drain region **102** and expose a portion of a top surface of the source/drain region **102**. A layer of conductive material (not shown) is then formed over the dielectric layer **112** and fills the opening **114**. The portion of the conductive material formed above the dielectric layer **112** is then removed by a sequential planarization step (not shown), thereby leaving a conductive electrode **116** in the opening **114**. The conductive electrode **116** may comprise conductive materials such as Al, Ti, TiN or W, having a diameter D_2 . A diffusion barrier layer (not shown) can be further formed between the conductive electrode **116** and the dielectric layers **112**, **108** and substrate **100** adjacent thereto, thereby preventing ions of the conductive materials of the conductive electrode **116** from diffusing into adjacent layers.

In FIG. 7, a dielectric layer **118** is next formed over the dielectric layer **112**, covering the dielectric layer **112** and the conductive electrode **116**. Next, a photolithography step and an etching step (both not shown) are sequentially performed through the use of a third photomask (not shown) to thereby form an opening **120** in the dielectric layers **118** and **112**. As shown in FIG. 7, the opening **120** passes through the dielectric layers **118** and **112** perpendicular to a top surface of the substrate **100** and stops on phase change material layer **110a**, thereby exposing a part of the phase change material layer **110a**. Herein, the opening **120** is formed with a circular configuration (not shown in FIG. 7 but shown in FIG. 9), having a diameter D_3 .

In FIG. 8, a layer of conductive material is next formed over the dielectric layer **118** and fills the opening **120**. The portion of the conductive material above the dielectric layer is then removed by a sequential planarization step (not shown), thereby leaving a conductive layer **122a** in the opening **120**. The conductive layer **122a** fills the opening **120** and may function as a conductive electrode which sequentially penetrates downward through the dielectric layers **118** and **112** and connects the phase change material layer **110a**. The conductive electrode **122a** may comprise conductive materials such as Al, Ti, TiN or W, having a diameter D_3 . A diffusion barrier layer (not shown) may be further formed between the conductive electrode **122a** and the dielectric layers **118**, **112** and the phase change material layer **110a** adjacent thereto,

thereby preventing ions in the conductive materials of the conductive electrode **122a** from diffusing into adjacent layers.

Next, a layer of conductive material is blanketly formed over the dielectric layer **118**. A photolithography step and an etching step are sequentially performed on the conductive material incorporating a fourth photomask (not shown), thereby forming a patterned conductive layer **122** over a part of the dielectric layer **118**. The conductive layer **122** may comprise conductive materials such as Al, Ti, TiN or W. Herein, the conductive layer **122** substantially covers the conductive electrode **122a** formed in the underlying dielectric layers to connect the conductive electrode **122a**.

FIG. **9** is a schematic diagram showing a top view of the structure illustrated in FIG. **8** and FIG. **8** illustrates a cross section taken along line **8-8** in FIG. **9**. As shown in FIG. **9**, the openings **120** and **114** are now formed with a circular configuration and have similar diameters (D_3 substantially equals to D_2). The conductive electrodes formed in these openings fully overlap the phase change material layer **110a**. Herein, the conductive electrode formed in the opening **114** may function as a heating electrode and the portion of the circumference surface of the conductive electrode penetrating the phase change material layer **110a** (see FIG. **8**) is now fully surrounded by the phase change material layer **110a**, having a contact area of about $\pi D_2 T$ therebetween.

Assuming the phase change material layer **110a** has a thickness T of about 10 nm and the conductive electrode formed in the opening **114** has a diameter D_2 of about 100 nm, a contact area of about $1000\pi \text{ nm}^2$ between the phase change material layer **110a** and a conductive electrode is provided. Compared with the conventional phase change memory cell illustrated in FIGS. **1** and **2**, the conventional memory cell structure may have a contact area of about $\pi D_1^2/4$ between the phase change material layer **20** and the heating electrode **16** and a contact area of about 2500π therebetween is provided while D_1 is 100 nm.

Thus, a contact area between the phase change material layer and the heating electrode in a phase change memory device of the invention is only about 0.4 times that in the conventional phase change memory device while using a heating electrode with similar diameter. An increased current density can be thus provided to the phase change material layer due to reduction of the contact area. Additionally, the current density provided to the phase change material layer in the invention can be controlled by adjusting a thickness of the phase change material layer, thereby solving issues of reduction of a heating electrode restricted by photolithography capability in conventional phase change memory cell manufacturing.

FIG. **10** is a schematic diagram illustrating another top view of the conductive electrodes formed in the openings **120** and **114**. As shown in FIG. **10**, the opening **114** is formed with a diameter D_2 larger than the diameter D_3 of the opening **120**. The opening **114** is also larger than a width of the phase change material layer **110a**. Thus, the conductive electrode formed in the opening **114** has a dimension larger than that formed in the opening **120** and the conductive electrode formed in the opening **114** not only penetrates the phase change material layer but also penetrates portions of the dielectric layers (e.g. the dielectric layers **108** and **112**) adjacent to the phase change material layer **110a**.

FIG. **11** is a schematic diagram illustrating another top view of the conductive electrodes formed in the openings **120** and **114**. As shown in FIG. **11**, the position of the opening **114** is shifted and a circumstance of the conductive electrode formed in the opening **114** contacting the phase change mate-

rial layer is not fully surrounded by the phase change material layer **110a**. Portions of the circumference of the portion of the conductive electrode formed in the opening **114** penetrating the phase change material layer **110a** are now surrounded by the adjacent dielectric layers. The conductive electrode formed in the opening **114** now merely penetrates portions of the phase change material layer **110a**.

Accordingly, the phase change memory device in the first embodiment can be taken as an active phase change memory device applied with an active device such as a transistor. In the first embodiment, the phase change memory cell structure therein can be formed through the uses of four photomasks, thereby having an advantage of easily fabrication. In this embodiment, the active device is not restricted to the transistor illustrated and can be other active devices such as a diode.

SECOND EMBODIMENT

FIGS. **12~16** are schematic diagrams showing different fabrication steps of a method for manufacturing a phase change memory device according to a second embodiment of the invention, respectively. In FIG. **12**, a semiconductor structure as illustrated in FIG. **6** of the first embodiment is first provided through fabrications as that illustrated in FIGS. **3-6**. Next, a dielectric layer **118** is blanketly formed over the dielectric layer **112** and the conductive electrode **116**. A photolithography step and an etching step (both not shown) are then performed to form an opening **120'** in the dielectric layer **118** and **112** through the use of a photomask (not shown). As shown in FIG. **12**, the opening **120'** is perpendicular to a surface of the substrate **100** and extends through the dielectric layer **118**, the dielectric layer **112** and portions of the dielectric layer **108**, thereby penetrating portions of the phase change material layer **110a**. Herein, the opening **120'** may have a circular configuration (shown in FIG. **14** but not shown in FIG. **12**), having a diameter D_3 .

As shown in FIG. **13**, a layer of conductive material is next formed over the dielectric layer **118** and fills the opening **120'**. The portion of the layer of conductive material above the dielectric layer **118** is then removed, thereby leaving a conductive layer **122a** in the opening **120'**. The conductive layer **122a** fills the opening **120'** and forms a conductive electrode penetrating downward through dielectric layers **118** and **112**, thereby connecting the phase change material layer **110a**. The conductive electrode **122a** may comprise conductive material such as Al, Ti, TiN or W and has a diameter D_3 . A diffusion barrier layer (not shown) can be further formed between the conductive electrode **122a** and the dielectric layer **118**, the dielectric layer **112** and the phase change material layer **110a** adjacent thereto, thereby preventing ions in the conductive materials of the conductive electrode **122a** from diffusing into adjacent layers.

Next, a layer of conductive material (not shown) is blanketly formed over the dielectric layer **118**. A photolithography step and an etching step (both not shown) are sequentially performed to the layer of conductive material through the use of a photomask (not shown), thereby forming a patterned conductive layer **122** over a part of the dielectric layer **118**. The conductive layer **122** may comprise conductive materials such as Al, Ti, TiN or W. Herein, the conductive layer **122** substantially covers the conductive electrode **122a** formed in the underlying dielectric layer and connects the conductive electrode **122a**.

FIG. **14** is a schematic diagram showing a top view of the structure illustrated in FIG. **13** and FIG. **13** illustrates a cross section taken along line **13-13** in FIG. **14**. As shown in FIG. **14**, the openings **120'** and **114** are now both formed with a

circular configuration and in a similar diameter (D_3 substantially equals to D_2). The conductive electrodes formed in these openings substantially fully overlap the phase change material layer **110a**. At this time, the conductive electrode formed in the opening **114** may function as a heating electrode and the circumference surface of the part of the conductive electrode penetrating the phase change material layer **110a** is fully surrounded by the phase change material layer, having a contact area of about $\pi D_2 T$.

FIG. **15** is another schematic diagram showing a top view of the conductive electrodes formed in the openings **120'** and **114**. As shown in FIG. **15**, the opening **114** is formed with a diameter D_2 similar to the diameter D_3 of the opening **120** but both thereof are larger than a width of the phase change material layer **110a**. Thus, the conductive electrode formed in the openings **114** and **120'** not only penetrates the phase change material layer but also penetrates portions of the dielectric layers (e.g. the dielectric layers **108**, **112** and **118**) adjacent to the phase change material layer **110a**.

FIG. **16** is a schematic diagram showing another configuration of the conductive electrodes formed in the openings **120'** and **114**. At this time, the opening **114** is formed with a diameter D_2 similar to the diameter D_3 of the opening **120'** however positions of the openings **114**, **120'** are shifted, portions of the circumference of the conductive electrode formed in the openings **114** and **120'** penetrating the phase change material layer are partially surrounded by the phase change material layer **110a** and portions of the circumference thereof is also surrounded by the adjacent dielectric layers. The conductive electrodes formed in the openings **114** and **120'** merely penetrate portions of the phase change material layer **110a**.

As shown by the embodiment, a contact area between the phase change material layer and the heating electrode in a phase change memory device of the second embodiment can be further reduced compared to the conventional phase change material cell while using a heating electrode of similar diameter. An increased current density can be thus provided to the phase change material layer due to reduction of the contact area. Additionally, the current density provided to the phase change material layer in this embodiment can be controlled by adjusting a thickness of the phase change material layer, thereby solving issues of reduction of a heating electrode restricted by photolithography capability in conventional phase change memory cell manufacturing.

THIRD EMBODIMENT

FIGS. **17**–**24** are schematic diagrams showing different fabrication steps of a method for manufacturing a phase change memory device according to a third embodiment of the invention, respectively. In FIG. **17**, a substrate **200**, for example a silicon semiconductor substrate, is first provided. Herein, an active device, such as a transistor, is also formed over the substrate **200**. As shown in FIG. **17**, the transistor has a pair of source/drain regions **202** formed in portions of the substrate **200** and a gate structure **204** formed over the portion of the substrate **200** between the source/drain regions **202**. As shown in FIG. **14**, the gate structure **204** may include a gate dielectric layer and a conductive layer but is merely illustrated as a gate structure **204** here for simplicity. A spacer **206** is disposed over opposing sidewalls of the gate structure **104**. The transistor illustrated in FIG. **17** may be a P type or an N type transistor and the source/drain regions **202** may comprise P type or N type impurities depending on the conductivity type of the transistor.

In FIG. **18**, a dielectric layer **208** is blanketly formed over the substrate **100**, covering the transistor. The dielectric layer **208** may comprise borophosphosilicate glass (BPSG), silicon oxide or spin on glass (SOG), and may be formed by methods such as chemical vapor deposition (CVD) or spin-on techniques. A photolithography step and an etching step (both not shown) are sequentially performed through the use of a first photomask (not shown) to pattern the dielectric layer **208**, thereby forming an opening **210** in a part of the dielectric layer **208**. Herein, the opening **210** penetrates the dielectric layer **208**, perpendicular to a top surface of the substrate **200**, thereby exposing a part of the substrate **200**. In some embodiments, the opening **210** may be formed in a circular configuration and having a diameter D_4 . In some embodiments, the opening **210** is substantially formed over one of the source/drain regions **202**, exposing a portion of a top surface of the source/drain region **202**.

In FIG. **19**, a layer of conductive material (not shown) is then formed over the dielectric layer **208** and fills the opening **210**. The portion of the conductive material formed above the dielectric layer **208** is then removed by a sequential planarization step (not shown), thereby leaving a conductive electrode **212** in the opening **210**. The conductive electrode **212** may comprise conductive materials such as Al, Ti, TiN or W, having a diameter D_4 . A diffusion barrier layer (not shown) can be further formed between the conductive electrode **212** and the dielectric layer **208** and substrate **100** adjacent thereto, thereby preventing ions of the conductive materials of the conductive electrode **212** from diffusing into adjacent layers. A layer of phase change material is next blanketly formed over the dielectric layer **208** and the conductive electrode **212**. The layer of the phase change material layer may comprise chalcogenide materials such as Ge—Sb—Te ternary chalcogenide compound or Ge—Te, Te—Sb binary chalcogenide compounds and can be formed by methods such as CVD or sputtering. Herein, the layer of phase change material may have a thickness T of about 50~1000 Å, preferably of about 100~150 Å. Next, a photolithography step and an etching step (both not shown) are sequentially performed through the use of a second photomask (not shown) to pattern the layer of the phase change material, thereby leaving a patterned phase change material layer **214** over a part of the dielectric layer **208**, substantially covering the conductive electrode **212**. Next, a dielectric layer **216** is formed over the dielectric layer **108** and covers the patterned phase change material layer **214** overlying the dielectric layer **208**. The dielectric layer **216** may comprise borophosphosilicate glass (BPSG), silicon oxide or spin on glass (SOG) and can be formed by methods such as chemical vapor deposition (CVD) or spin-on techniques.

As shown in FIG. **20**, a photolithography step and an etching step (not shown) are sequentially performed through the use of a third photomask (not shown) to thereby define the dielectric layer **216**, the phase change material layer **214** and the dielectric layer **208**, thereby forming an opening **220** in a part of these layers. Herein, the opening **220** sequentially penetrates the dielectric layer **216**, the phase change material layer **214** and portions of the dielectric layer **208** perpendicular to a top surface of the substrate **200**, thereby laterally exposing a part of the phase change material layer **214**. In some embodiments, the opening **220** may be formed in a circular configuration (not shown in FIG. **20** but shown in FIG. **22**), having a diameter D_5 .

In FIG. **21**, a layer of conductive material (not shown) is then formed over the dielectric layer **216** and fills the opening **220**. The portion of the conductive material formed above the dielectric layer **216** is then removed by a sequential planariza-

tion step (not shown), thereby leaving a conductive electrode **222a** in the opening **220**. The conductive electrode **222a** may comprise conductive materials such as Al, Ti, TiN or W, having a diameter D_5 . A diffusion barrier layer (not shown) can be further formed between the conductive electrode **222a** and the dielectric layers **216**, **208** and phase change material layer **214** adjacent thereto, thereby preventing ions of the conductive materials of the conductive electrode **222a** from diffusing into adjacent layers.

Next, a layer of conductive material is blanketly formed over the dielectric layer **216**. A photolithography step and an etching step are sequentially performed to the conductive material incorporating a fourth photomask (not shown), thereby forming a patterned conductive layer **222** over a part of the dielectric layer **216**. The conductive layer **222** may comprise conductive materials such as Al, Ti, TiN or W. Herein, the conductive layer **222** substantially covers the conductive electrode **222a** formed in the underlying dielectric layers to connect the conductive electrode **222a**.

FIG. **22** is a schematic diagram showing a top view of the structure illustrated in FIG. **21** and FIG. **21** illustrates a cross section taken along line **21-21** in FIG. **22**. As shown in FIG. **22**, the openings **220** and **210** are now formed with a circular configuration and have different diameters (D_4 substantially larger than D_5). The conductive electrodes formed in these openings fully overlap the phase change material layer **214**. Herein, the conductive electrode formed in the opening **220** may function as a heating electrode and the portion of the circumference surface of the conductive electrode penetrating the phase change material layer **214** (see FIG. **21**) is now fully surrounded by the phase change material layer **214**, having a contact area of about $\pi D_5 T$ therebetween.

FIG. **23** is a schematic diagram illustrating another top view of the conductive electrodes formed in the openings **210** and **220**. As shown in FIG. **23**, the opening **220** is formed with a diameter D_5 larger than the diameter D_4 of the opening **210**. The diameter D_5 of the opening **220** is also larger than a width of the phase change material layer **214**. Thus, the conductive electrode formed in the opening **220** has a dimension larger than that formed in the opening **210** and the conductive electrode formed in the opening **220** now not only fully penetrates the phase change material layer but also penetrates portions of the dielectric layers (e.g. the dielectric layers **216** and **208**) adjacent to the phase change material layer **214**.

FIG. **24** is a schematic diagram illustrating another top view of the conductive electrodes formed in the openings **210** and **220**. As shown in FIG. **24**, the position of the opening **220** is shifted and a circumference of the conductive electrode formed in the opening **220** contacting the phase change material layer is not fully surrounded by the phase change material layer **214**. Portions of the circumference of the portion of the conductive electrode formed in the opening **220** penetrating the phase change material layer **214** are now surrounded by the adjacent dielectric layers. The conductive electrode formed in the opening **220** now merely penetrates portions of the phase change material layer **214**.

As shown by the embodiment, a contact area between the phase change material layer and the heating electrode in a phase change memory device of the third embodiment can be further reduced compared to the conventional phase change material cell illustrated in FIG. **1** while using a heating electrode of similar diameter. An increased current density can be thus provided to the phase change material layer due to reduction of the contact area. Additionally, the current density provided to the phase change material layer in this embodiment can be controlled by adjusting a thickness of the phase

change material layer, thereby solving issues of reduction of a heating electrode restricted by photolithography capability in conventional phase change memory cell manufacturing.

FOURTH EMBODIMENT

The first, second and third embodiments as disclosed are exemplary embodiments showing a phase change memory device having an active device formed therein but the phase change memory device of the invention is not limited thereto. The phase change memory device of the invention can be formed as a passive phase change memory device without active devices formed therein, as illustrated in FIGS. **25-27**.

FIG. **25** is a schematic diagram showing a cross section of a phase change memory device, comprising a substrate **300**, a conductive layer **302** formed over the substrate **300**, a plurality of dielectric layers **304**, **306** and **312** sequentially formed over the conductive layer **302**, and a conductive layer **316** formed over the dielectric layer **312**.

As shown in FIG. **25**, a conductive electrode **310** is disposed in the dielectric layers **304** and **306**, a phase change material layer **308** is disposed in the dielectric layer **306**, and a conductive electrode **314** is disposed in the dielectric layers **306** and **312**. The conductive electrode **310** now penetrates a part of the phase change material layer **308** and electrically connects the conductive layer **302** and the phase change material layer **308**. The conductive electrode **314** electrically connects the conductive layer **316** and the phase change material layer **308**. Fabrication of the conductive electrodes **314** and **310**, and the phase change material layer **308** can be achieved by fabrications illustrated in FIGS. **3-8**. Configurations of the conductive electrodes **314** and **310**, and the phase change material layer **308** maybe the same as those illustrated in FIGS. **9-11**. Herein, the conductive electrode **310** functions as a heating electrode and the conductive layer **302** is formed over the substrate prior to formation of the dielectric layer **304**. Fabrications of the conductive layer **316** and the conductive electrode **314** maybe the same as fabrication illustrated in FIGS. **7-8**.

Moreover, FIG. **26** illustrates another configuration of the phase change memory device according to another embodiment of the invention. In this embodiment, the conductive electrodes **314** and **310** respectively penetrates a part of the phase change material layer **308** either downward or upward, both thereof functioning as heating electrodes. Fabrication of the conductive electrodes **314** and **310** and phase change material layer **308** can be achieved by fabrication illustrated in FIGS. **12** and **13** and may have configurations as those illustrated in FIGS. **14-16**.

In addition, FIG. **27** illustrates yet another configuration of the phase change memory device according to another embodiment of the invention, having two conductive electrodes **314** and **310** therein. In this embodiment, the conductive electrode **314** penetrates a part of the phase change material layer **308** downward and functions as a heating electrode. Fabrication of the conductive electrodes **314** and **310** and phase change material layer **308** can be achieved by fabrication illustrated in FIGS. **17-21** and may have configurations as those illustrated in FIGS. **22-24**.

While the invention has been described by way of example and in terms of preferred embodiment, it is to be understood that the invention is not limited thereto. To the contrary, it is intended to cover various modifications and similar arrangements (as would be apparent to those skilled in the art). Therefore, the scope of the appended claims should be accorded the broadest interpretation so as to encompass all such modifications and similar arrangements.

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What is claimed is:

1. A phase change memory device, comprising:
a substrate;
a dielectric layer formed over the substrate;
a phase change material layer embedded in the dielectric layer; and
a first conductive electrode embedded in the dielectric layer, penetrating the phase change material layer and extending perpendicular to a top surface of the dielectric layer.
2. The phase change memory device as claimed in claim 1, wherein the phase change material layer surrounds a part of the first conductive electrode along a circumference of the first conductive electrode.
3. The phase change memory device as claimed in claim 1, wherein the phase change material layer comprises chalcogenide materials.
4. The phase change memory device as claimed in claim 1, wherein phase change material layer is disposed in the dielectric layer and extends in the dielectric layer along a direction horizontal to a top surface of the dielectric layer.
5. The phase change memory device as claimed in claim 1, further comprising a first conductive layer disposed between the substrate and the dielectric layer, wherein the first conductive electrode connects the first conductive layer.
6. The phase change memory device as claimed in claim 5, further comprising a second conductive layer disposed over the dielectric layer to electrically connect the phase change material layer.

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7. The phase change memory device as claimed in claim 6, further comprising a second conductive electrode disposed in the dielectric layer to electrically connect the phase change material layer and the second conductive layer.
8. The phase change memory device as claimed in claim 1, further comprising an active device disposed over the substrate and covered by dielectric layer, wherein the first conductive electrode connects the active device.
9. The phase change memory device as claimed in claim 8, wherein the active device is a transistor and the first conductive electrode connects a source/drain region of the transistor.
10. The phase change memory device as claimed in claim 9, further comprising a conductive layer disposed over the dielectric layer to electrically connect the phase change material layer.
11. The phase change memory device as claimed in claim 6, further comprising a second conductive electrode disposed in a second part of the dielectric layer to connect the phase change material layer with the conductive layer.
12. The phase change memory device as claimed in claim 11, wherein the second conductive electrode penetrates the phase change material layer perpendicular to a top surface of the dielectric layer and the phase change material layer surrounds a part of the second conductive electrode along a circumference of the second conductive electrode.

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